700 kW Proton Beam for Neutrinos:

The Recycler as a Proton Pre-Injector

Paul Derwent
Fermilab AAC

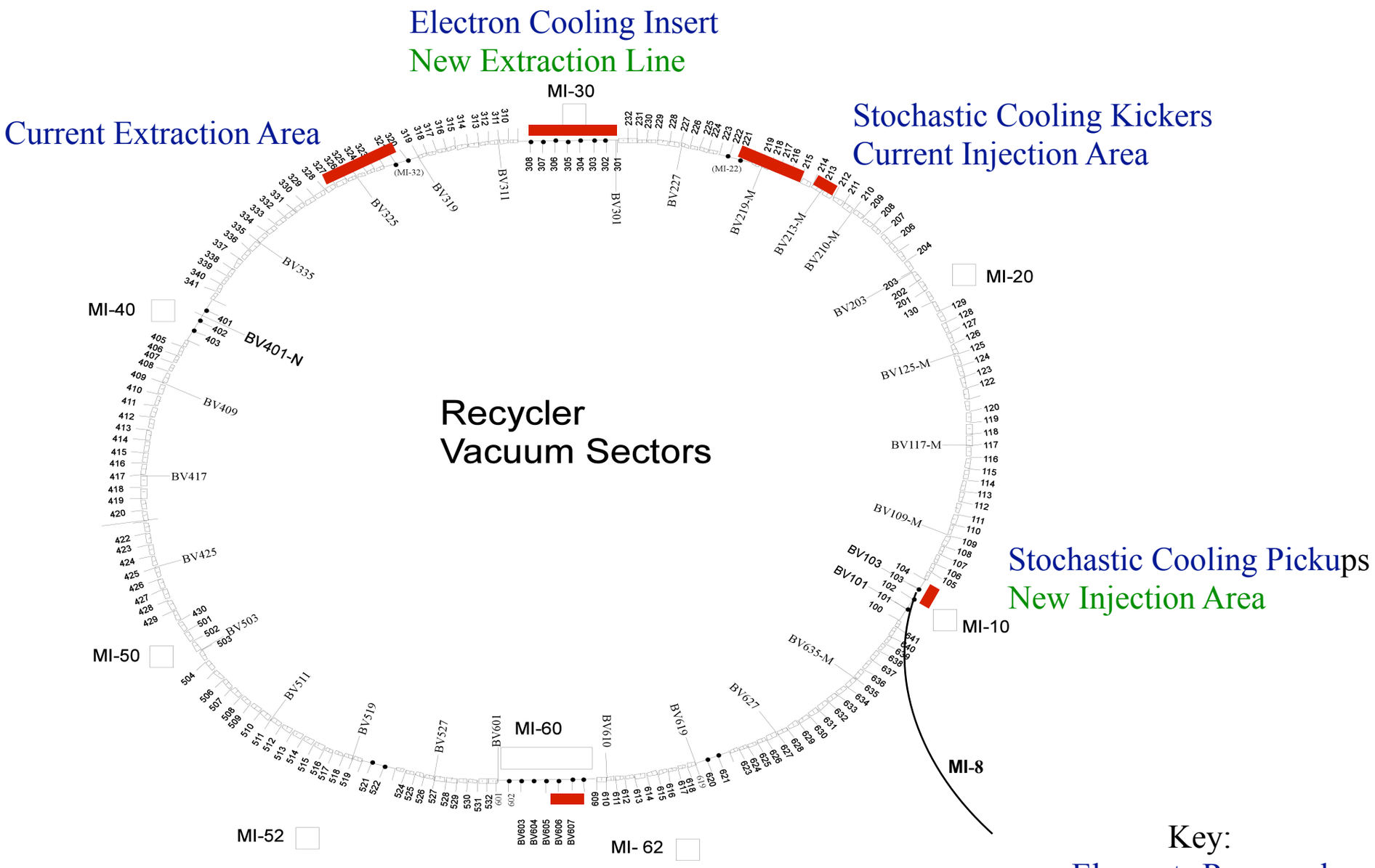
The Recycler as Proton Pre-Injector

- The Recycler is the TeV Collider Anti-Proton Storage Bottle
  - Lifetime ≥ 500 hours
  - Stochastic and Electron Cooling
  - >4e12 circulating anti-protons (~1.2e13 protons)
  - Good Transverse and Momentum Aperture
    - ~65 π mm mr Transverse Acceptance
    - ~1.5% Momentum Acceptance
- The Recycler as Proton Pre-Injector
  - Same Size as MI: Single turn fill time (~11 μsec)
  - Good Transverse and Momentum Acceptance
    - Slip or Boxcar stack to accumulate proton current

What needs to be done to convert

- Take antiproton specific devices out
  - Stochastic cooling
  - Electron cooling
- Build new transfer lines
  - direct injection into RR
    - currently only injection is through MI
    - needs fast kicker!
  - new extraction line
    - larger aperture (~20 π protons vs ~5 π anti-protons)
    - needs 2 new 11 μsec kickers!
- 53 MHz RF system for slip stacking
- Instrumentation!

Recycler Layout



Removal of Pbar Specific Components

- Straightforward: Time & Effort for the tasks
  - Electron Cooling Insert: Remove solenoids, install FODO lattice
    - ~50 Days
    - 8 Techs (Vacuum/ Mechanical)
  - Stochastic Cooling: Remove Pickups and Kickers
    - ~21 Days
    - 8 Techs (Vacuum/Mechanical)
  - Current Injection/Extraction Lines: Removal of components
    - ~21 Days
    - 8 Techs (Vacuum/Mechanical)

  - Parallel tasks (in general): Different locations in the ring
    - Constraint: 3 Magnet movers
    - Recycler is hung from the ceiling

Injection Line

- Want Direct 8 GeV injection into Recycler
  - currently go through MI
  - adjust Booster & MI '8 GeV' to match Recycler -- ~40 MeV different

- Want to also:
  - Preserve Direct 8 GeV injection into MI

  - Preserve 8 GeV Booster Neutrino Beam

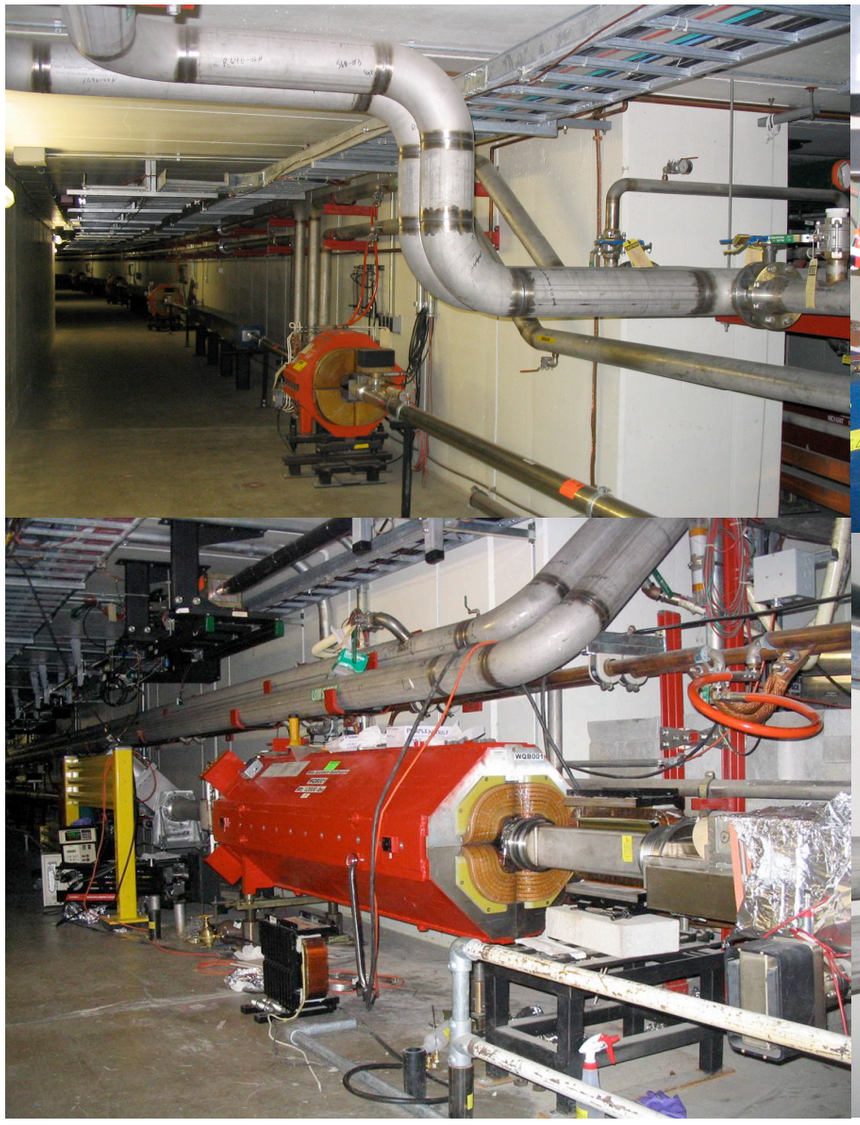
- Follow existing MI-8 line, use vertical switcher magnet to send to Recycler
  - looking at 2 options

- Busy area: engineering work to handle necessary infrastructure

Injection Line Area

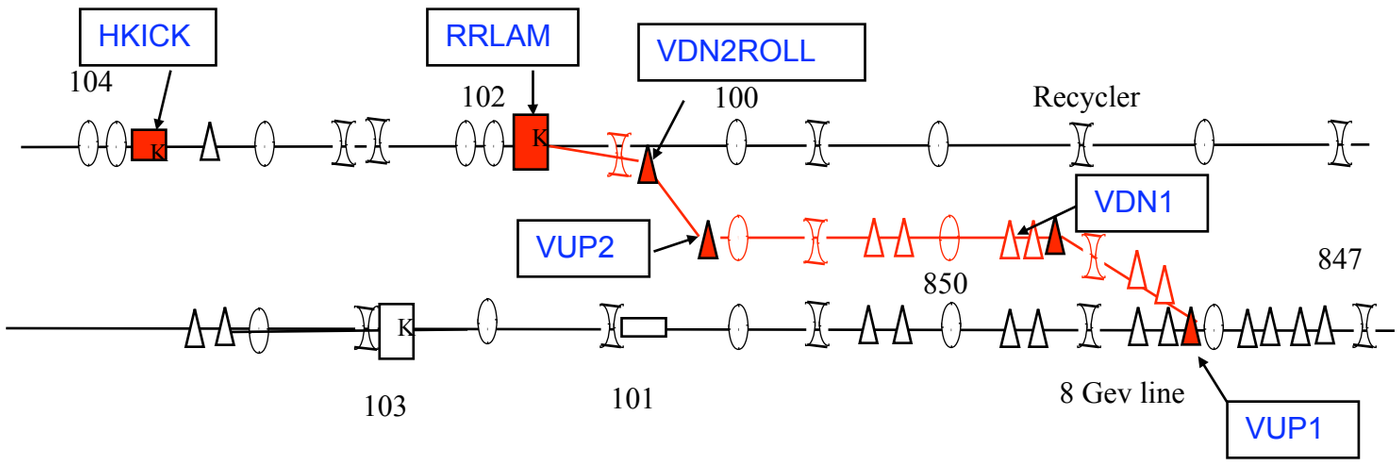
MI 8

MI 8 and Main Injector



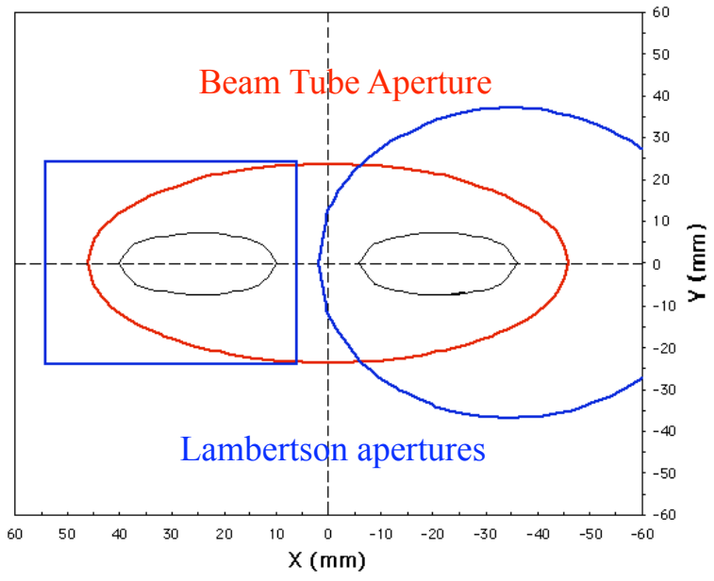
MI and Recycler and Infrastructure

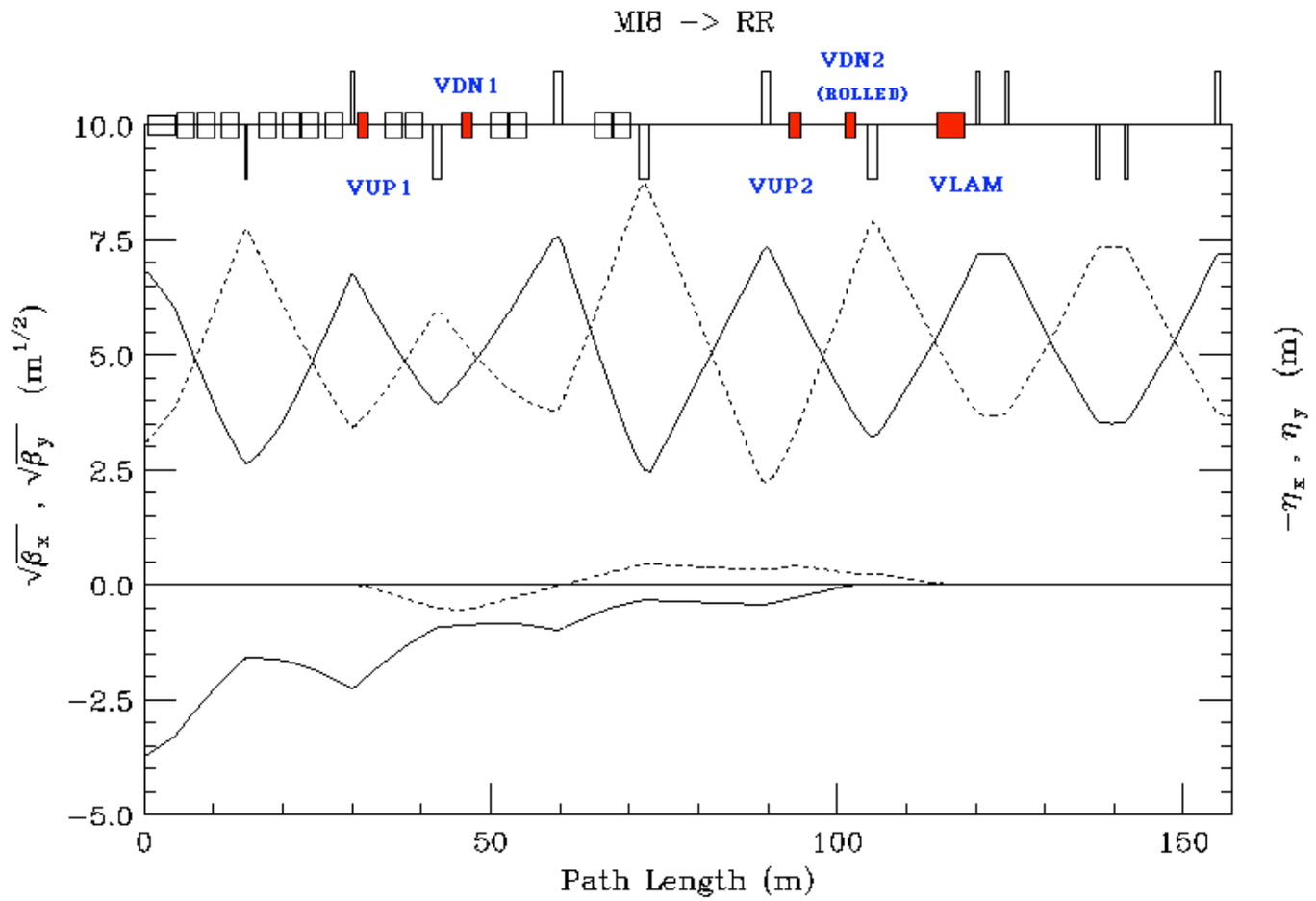
New Injection Line 1



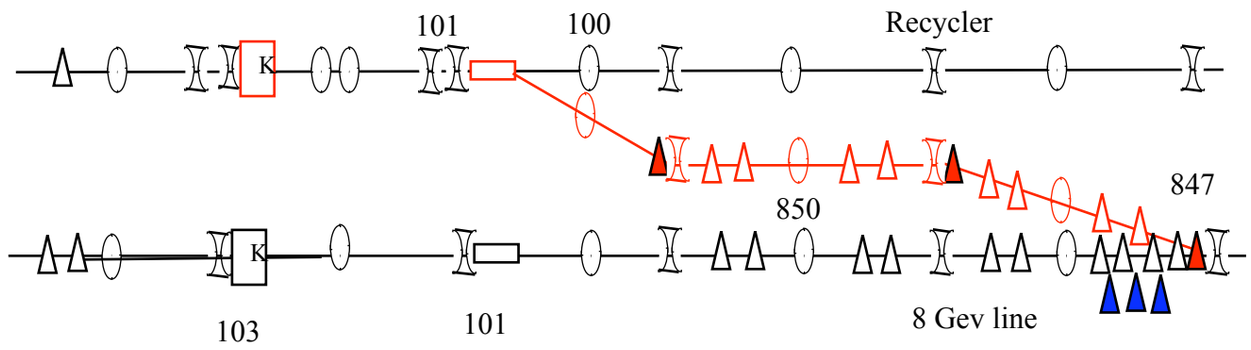
Follow the trajectory of existing MI-8 line to MI, but use a switch magnet to bend the beam up in two levels to RR

Horizontal kicker: Recycler elliptical aperture
Rise and fall time specification -- more expensive!





New Injection Line 2

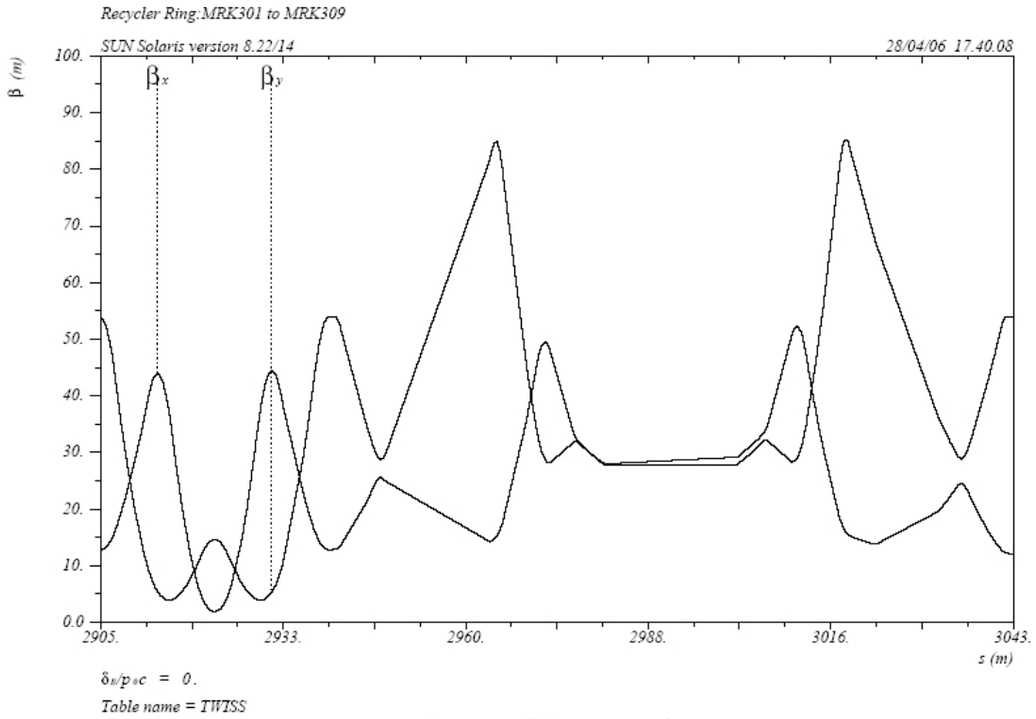


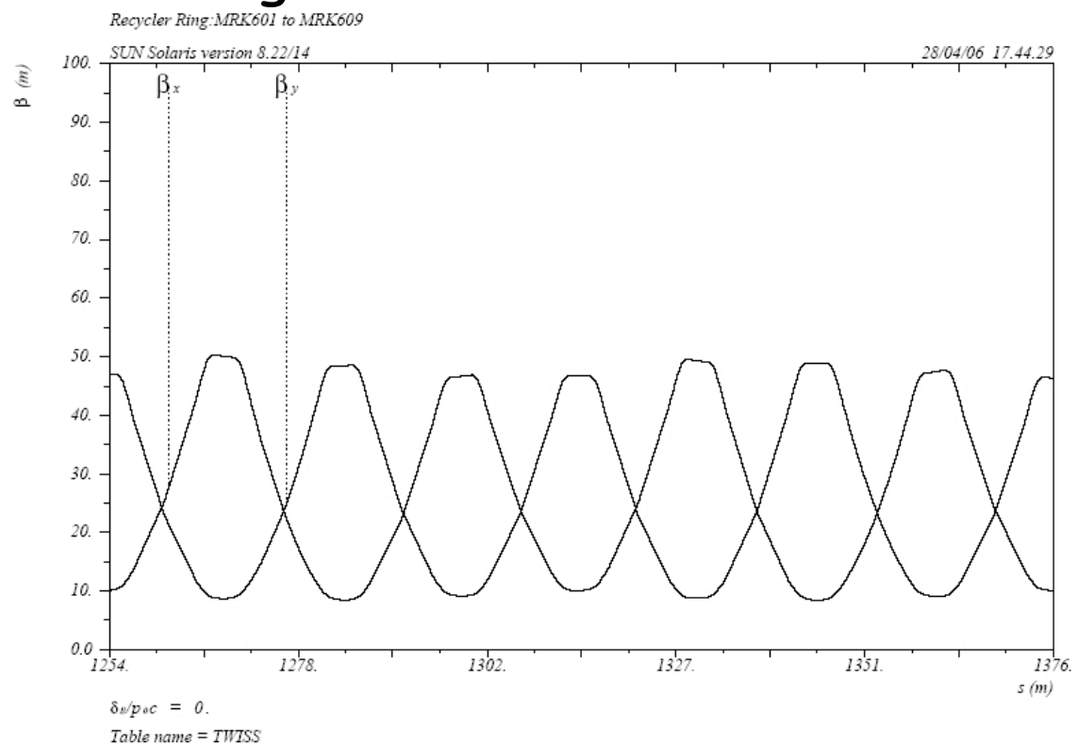
- Switcher magnet as a vertical dipole located at 847 in the 8 GeV line with vertical (MI10 style) Lambertson at Q101 and vertical kicker at Q103.
  - Vertical kicker -- may be easier to meet rise/fall specifications
- Replacing 4 PDD permanent magnet dipoles in 847 half cell by 3 reduced gap 4-4-30 dipoles (run DC), but keeping the same bending center and angle in about 1/3 the length, it could make room to put a vertical dipole.

For both options magnets for the transfer line have been identified

New Extraction Line

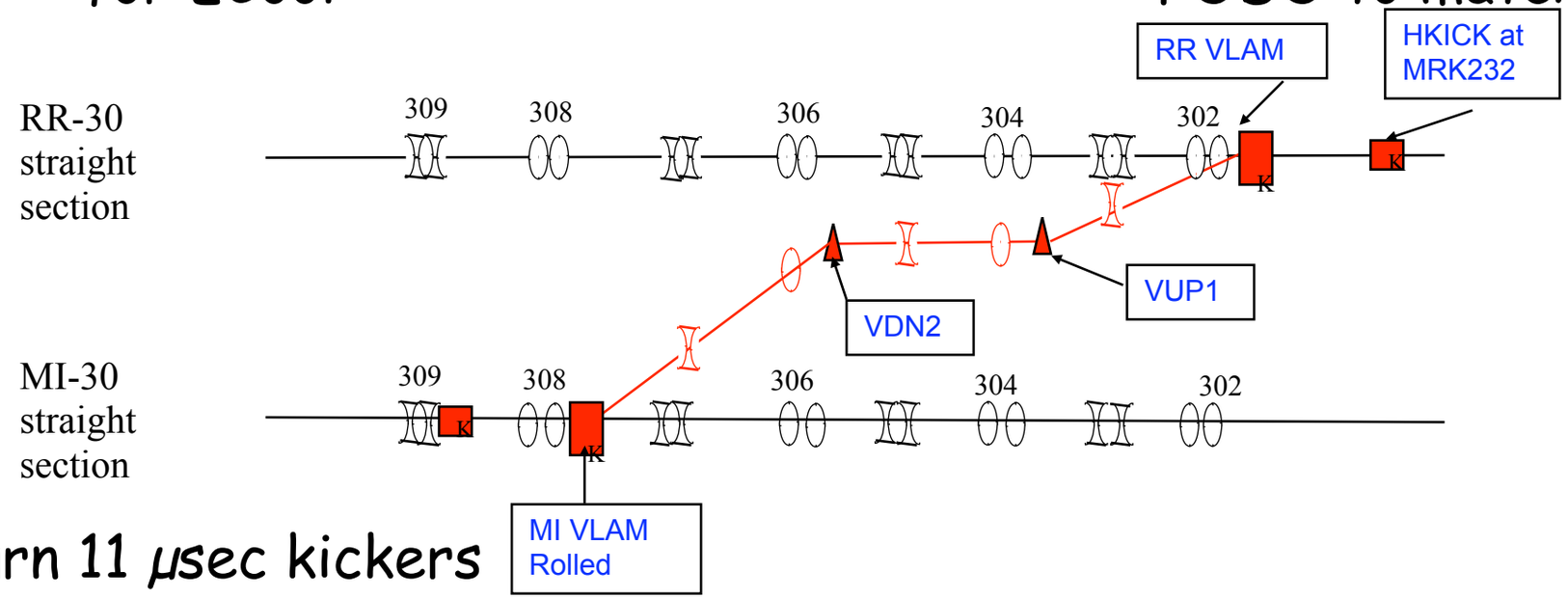
Special lattice insert at RR30 for Electron Cooling: Revert to FODO





for ECool

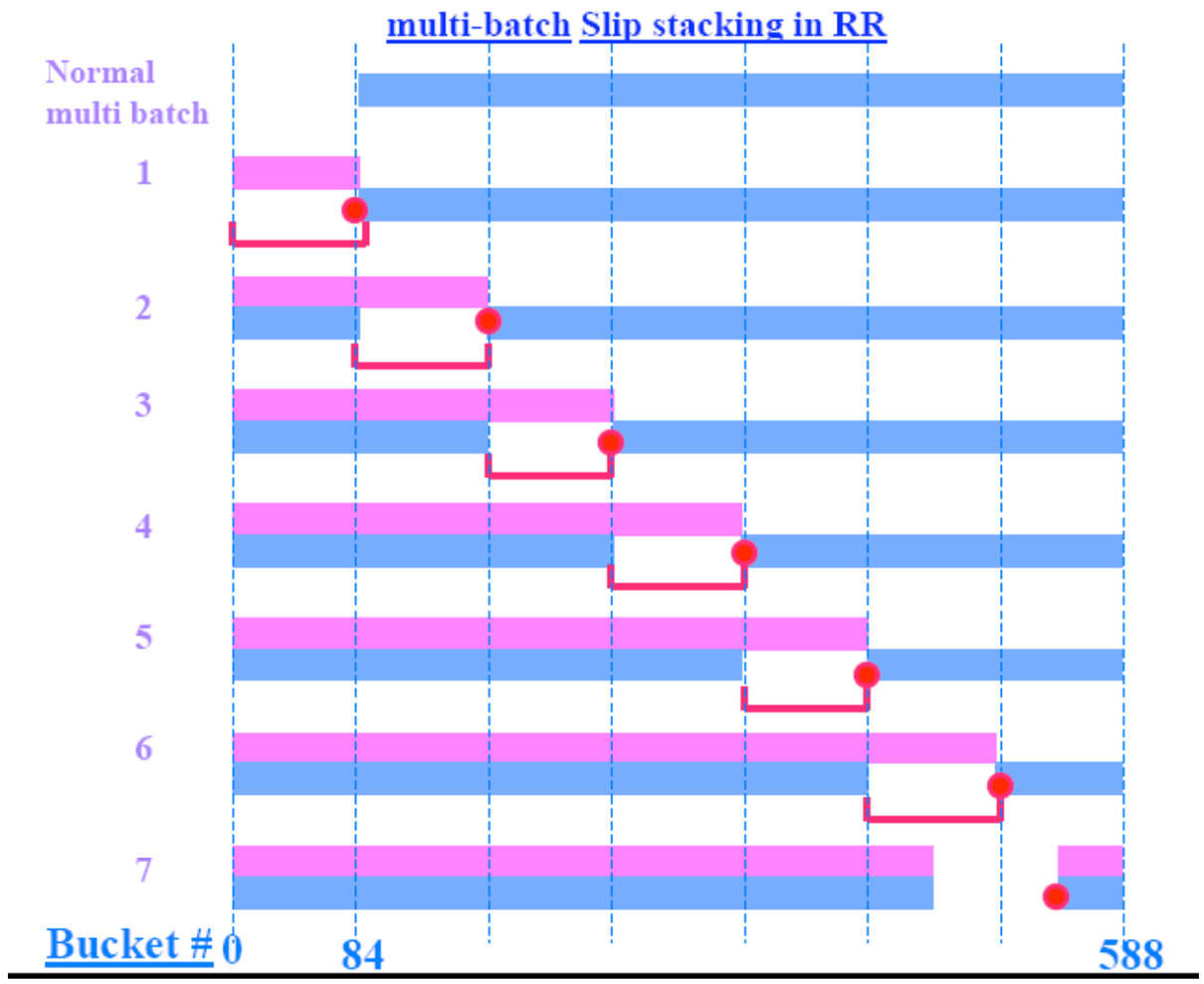
FODO to match MI



2 Single turn 11 μsec kickers

Slip Stacking in the RR

- 1.5% momentum aperture
- Two RF systems
  - 52.809 MHz ± 1300 Hz
  - 150 kV each
- Transient beam loading compensation is crucial
- Constraints on kicker rise/fall times!



I. Kourbanis, K. Seiya, beams-doc-2179

New 53 MHz RF Cavities for Slip Stacking

- List of Design Parameters compiled
- Propose to build 4 New RF Cavities
  - Two for Slip Stacking
  - Two for 1 MW phase

  - Recycle TeV RF Power Amps (200 kW)
    - Place amps in tunnel

  - Recycle TeV Modulators

  - For Anode Supply
    - Piggy back off MI Anode Supply
    - Use TeV Anode Supply if needed

- Cost Estimate:
  - $800k for Cavities
  - $200k for installation (electricians and pipe fitters) and infrastructure

Instrumentation

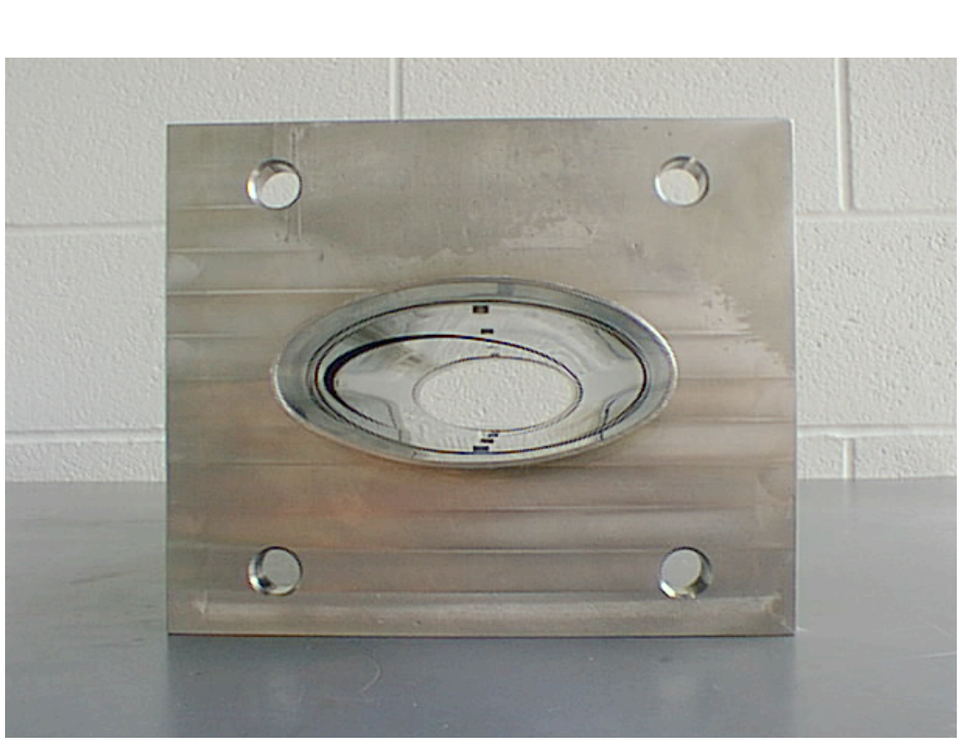
- DCCT : radiation and new controller
- Dampers
- BPMs:
  - Split Beam Tube Design

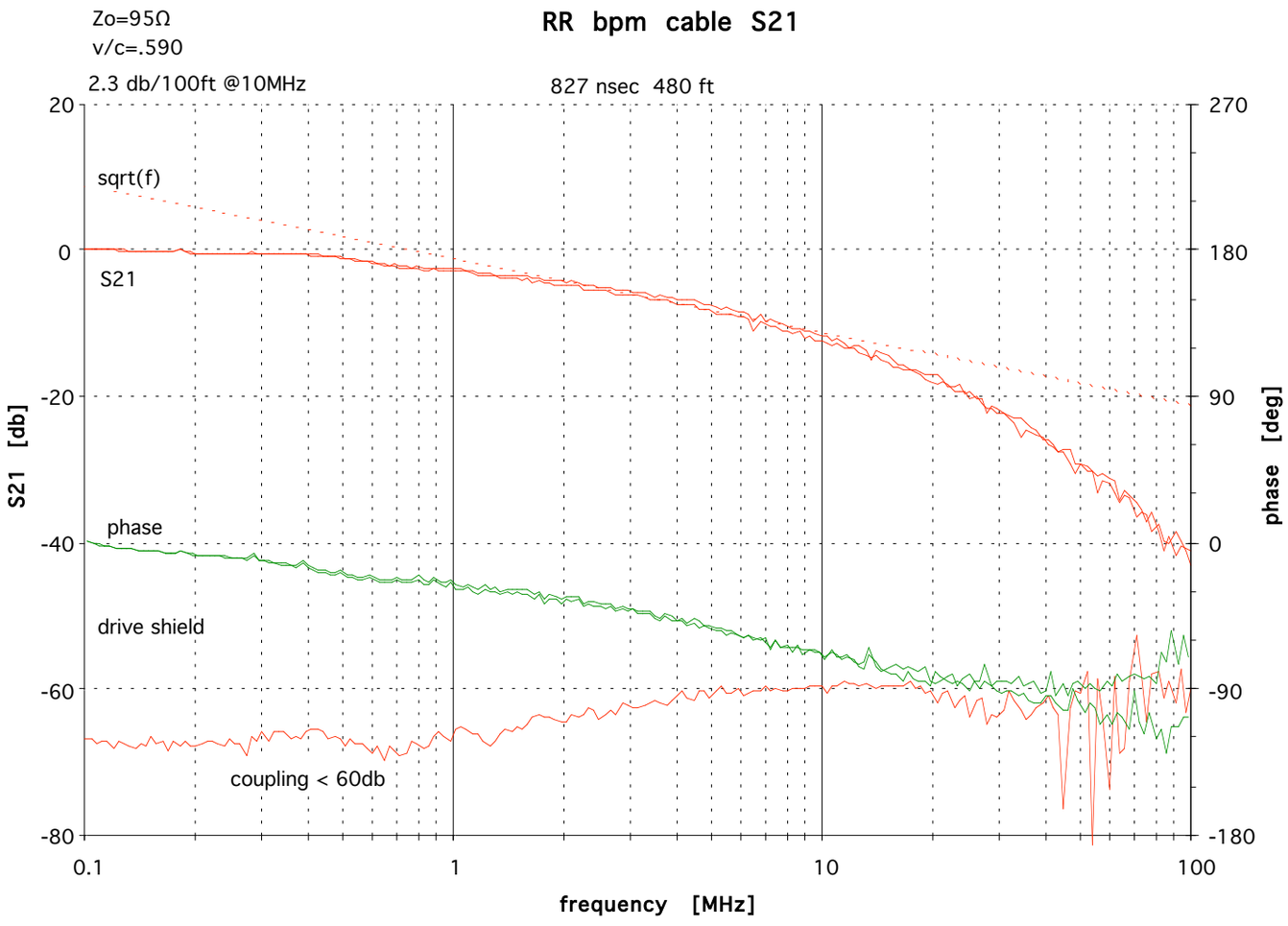
    ok at 53 MHz
  - Long Twisted Pair Cables :

    up to 1300 ft

    not so good at 53 MHz

    PreAmps: Radiation?





Kickers

- Need 5 NEW kickers: Major cost and schedule issue
  - Injection Line:
    - Fast Rise and Fall Time
    - Horizontal vs Vertical
  - 2 for Extraction Line (1 in RR, 1 in MI)
    - 11 μsec full turn
    - similar to current NuMI kickers
  - Full turn abort kicker in RR
    - just like above
  - Clean up kicker in RR
    - used to remove beam not captured in slip stacking in gap
    - fast rise and fall time
    - similar to injection line kickers
- ~$2.5M total
- Specifications in progress to get cost and schedule estimates

Preliminary Cost details

	Cost (k$)
Decommissioning anti-proton devices	100
New Injection Line	800
New Extraction Line	1200
Rework MI 31 Straight	100
Abort Line	1000
53 MHz RF System	1000
Dampers	300
Instrumentation (DCCT, BPMs, etc)	500
Infrastructure	600
People Power	100
7.5 MHz RF (for 1 MW option)	1000
Total	6700

Conclusion

- Recycler as Proton Pre-Injector
  - support single turn injection into MI
  - large transverse and momentum aperture
  - Reconfigure
    - Injection
    - Extraction
    - RF system
    - Instrumentation

- Begun design steps to convert from an anti-proton storage machine to proton injector for 700 kW neutrino program

Design Parameters

λ/4 coaxial design (25" OD)
OFHC copper
Step-up ratio = 6:1
fo = 52.809 MHz
Q ~ 7000
Tunable over +/- 10 kHz range using fast (4 turns) garnet phase shifters developed for the Proton Driver
Rsh = 140 kΩ -- 80 kW/cavity at 150 kV
R/Q = 20Ω
Tetrode anode dissipation with 1 A_{dc} beam current and no detuning = 130 KW (tube rated for 150 kW)
HOM dampers for 3rd & 5th harmonics

Why not use TeV RF Cavities?

Wrong Frequency (53.105 MHz)
Tuning rate of 1 kHz/s
Radioactive
Multipactor up to 90 kV
Shunt impedance of > 1 MΩ
(1 amp beam gives 1 MV without feedback)
R/Q ~ 170 (big transient loading)
No HOM dampers